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Phantom based kV-CBCT dose plan calculations for re-planning decision: comparison with CT-based dose plans

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Objective
CBCTs are helpful for patients positioning and viewing anatomical changes. This study investigates, on an anthropomorphic phantom, with no movement and anatomical changes, the possibility and accuracy of using CBCT-based dosimetry for re-planning decision.

Materials
Rando phantom’s brain, H&N, thorax and pelvis were scanned. Targets and main OAR were contoured. IMRT was used for H&N and VMAT for brain, lung and pelvis. Dose distributions were calculated using Eclipse 10.0 AAA Algorithm. CBCT scans were acquired per region on a Novalis Tx. After registration with the reference CT, structures were copied and dosimetric plans were recalculated on the CBCT. The DVH for targets and OAR and 2D dose maps were compared. Furthermore the HU to electron density curves for the different CBCT protocols were obtained using a Catphan® 504 phantom. To end examples of patients with anatomical changes are presented.

Results
PTV and OAR average mean dose differences for the brain, H&N, lungs and pelvic region were -1.1±0.7%, -0.6±0.4%, -0.9±1.0% and 0.1±0.5% respectively. Passing rate superior than 98% was achieved (gamma index criteria of 2%/1mm) for absolute 2D CBCT and CT-based dose distributions. CBCT HU to ED curves were within ±30 HU compared with the reference HU of the materials contained inside phantom, amply inside requested CT tolerance values.

Conclusion
Decision to re-plan VMAT or IMRT treatments seems feasible using CBCT data. Future investigations on the HU to ED curve and curve stability will be done with the help of a CBCT electron density phantom (CIRS).
First experimental results of motion mitigation by continuous line scanning

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Objective
Scanned proton therapy is sensitive to tumour motion due to the interplay effect. Rescanning is a promising technique to deal with this. Simulations indicate that rescanning with continuous line scanning would be best. We present its implementation and first experimental results and compare it to discrete spot scanning.

Materials
Contrary to spot scanning, in line scanning dead time is minimised by keeping the beam on between scan positions. The dose rate is modulated by scanning speed and beam intensity. This makes precise dose control far more challenging than for spot scanning. A spherical target of 270ml volume was applied to a plexiglass stack with spot and line scanning. The target is rescanned by dividing the proton fluence by the number of rescans. Two-dimensional dose distributions were imaged by a CCD camera system. Tumour motion was simulated by a programmable platform, with a peak-to-peak amplitude of 10 mm.

Results
Dose difference between discrete spot and line scanning was below 0.6 ± 0.5 % for up to 20 rescans. The penumbra along the scan direction was insignificantly larger for line scanning. Already 10 rescans were sufficient to mitigate tumour motion for both scanning techniques. Line scanning reduced the treatment time from 150s to 55s. D5-D95 could be reduced from 20% to 5%. All hot or cold spots could be eliminated.

Conclusion
Line scanning could be shown to mitigate tumour motion of even 10mm as well as discrete spot scanning, while being about three times faster. For larger motion, rescanning should be combined with other motion mitigation techniques in order to achieve sufficient dose homogeneity.
Impact of respiratory-correlated CT reconstruction algorithms in the choice of margin definition for free breathing lung treatment

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Objective
To investigate the impact of phase- and amplitude-based reconstruction algorithms in 4D treatment margin strategies in presence of respiratory irregularities.

Materials
4D CT images of Dynamic Thorax Phantom were acquired. Three irregular breathing patterns were simulated: amplitude, frequency, and combined amplitude and frequency variations. 4D CT image artifacts were analysed for the phase-and amplitude based reconstruction algorithms. To assess the impact of the 4D CT image artifacts on the dose distribution, twelve plans (three simulated breathing models for the two reconstruction algorithms and for the two margins strategies) were calculated with a Monte Carlo based TPS.

Results
The amplitude-based reconstruction shows a significant reduction of artifacts compared to the phase-based only for breathing amplitude variations. Most of the observed artifacts are image blurring and incomplete structures. The dosimetric analysis shows that the mid-ventilation strategy provides better tumor coverage than the ITV-based strategy.

Conclusion
Amplitude-based reconstruction reduces image distortions in the case of amplitude variations but not when frequency variations are present. Based on the impact of image artifacts and on dose distributions we showed that the mid-ventilation strategy is more robust than the ITV-based strategy.
Adequate margin definition for scanned particle therapy in the incident of intra-fractional motion

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Objective
4D dose calculations (4DDC) for scanned particle therapy show that in the incidence of motion, it is insufficient to use target contours defined on a reference CT. Variations in size, shape and position of CTVs relative to anatomic reference points have to be considered for internal target volumes (ITVs). In addition to geometrical margin adaption, changes of water equivalent path length have to be considered for particle therapy.

Materials
For 6 representative patients geometrical ITVs (gITV) were calculated by combining deformed CTVs over all motion phases. To take into account path length changes, range adapted ITVs (raITV) were established as the union of range adapted CTVs in all phases. For gated delivery, gat_gITVs and gat_raITVs were calculated. 4DDC have been performed for two exemplary patients to show effects of motion and to illustrate the necessity for appropriate margins.

Results
CTV’s significantly differ from gITVs/raITVs. raITVs and gITVs differ in size and are spatially displaced, particularly for lung patients and raITVs also show a strong field dependency in shape. All volumes are reduced in size when gating is applied. 4DDC results show big improvements if gITV or raITV are used compared to CTVs. However, the use of either gITVs or raITVs do not result in significant differences.

Conclusion
Our results emphasize that adapted target volumes have to be used for scanned particle therapy in the presence of motion. However, even though gITV’s and raITV’s differ significantly in shape and size, this difference does not necessarily translate into significant differences in the resultant 4D dose distributions.
Suitability of flattening filter free hybridarc for stereotactic radiosurgery

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Objective
HybridArc is a technique combining modulated arc fields with IMRT fields along these arcs. The aim of this work was to investigate the suitability of HybridArc using the TrueBeam equipped with a HD-MLC in the flattening filter free (FFF) mode for stereotactic radiosurgery and to compare it with HybridArc using the conventional flattening filter (FF) mode.

Materials
For 10 patients with brain metastases, HybridArc plans were generated using the FFF mode as well as the FF mode. The dose distributions were analyzed and compared according to homogeneity (HI=(D2%-D98%)/D Prescription*100%) and conformity (CI=prescription isodose volume/target volume) to the target. The dose to normal tissue and the total number of monitor units (MUs) per plan were investigated.

Results
The mean HI decreased from 4.0%±0.4% for the FF-HybridArc to 2.2%±0.3% for the FFF-HybridArc plans. The mean CI was the same for both methods: 1.35±0.12 and 1.33±0.14 for the FF-HybridArc and FFF-HybridArc, respectively. The number of MUs per plan decreased by 9% using FFF-HybridArc plans compared to FF-HybridArc plans. The maximum and the mean dose in the normal tissue decreased by up to 3% when using FFF-HybridArc instead of FF-HybridArc.

Conclusion
FFF-HybridArc is a suitable method for stereotactic radiosurgery. In comparison to the conventional FF-HybridArc method the dose homogeneity in the target volume is improved, the conformity remains the same, the total number of MUs is decreased and the normal tissue sparing is improved.
Deformation Evaluation using CBCT for Dynamic Adaptive Radiotherapy (DART) in Patients with Prostate Cancer: A Planning Study.

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Objective
Image-guided Radiotherapy (IGRT) for prostate cancer (PC) using fiducial markers (FM) takes organ motion but not deformation into account. Prostate deformation might lead to underdosage of PTV.

Materials
Five patients with PC were treated with IGRT using FM and endorectal balloon (ERB). For each patient planning-CT was compared to 3 CBCT at different stages during treatment. Organs of interest were contoured (Eclipse®) independently by 2 radiation oncologists (RO). Volumes of prostate, rectum, bladder and seminal vesicle (SV) and distances between rectum-symphysis, rectum-bladder and bladder-penile bulb were measured for correlation analysis. A conformity index (CI) between planning-CT and CBCT’s was determined.

Results
Prostate deformation was largest in posterior and cranial direction whereas contouring error was largest in anterior and caudal direction. Mean deviations between prostate contour on planning-CT and CBCT were 2.07 mm, 2.86 mm, 2.36 mm, 2.08 mm, 2.89 mm, 2.42 mm in anterior, posterior, left, right, cranial and caudal direction. The CI generally tended to worsen throughout treatment. Bladder filling correlated weakly (R²=0.25) with posterior deformation. Volumes of SV increased during RT in 4 out 5 patients.

Conclusion
Dynamic adaptive RT (DART) for prostate deformation correction has the potential to be beneficial for PTV coverage, particularly in posterocranial direction in supine position.
Advanced Hyperthermia Cancer Treatment Planning System

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Objective
Hyperthermia (HT, heating tumor tissue to ideally above 43°C), has been shown to strongly enhance radio- and chemotherapy for various types of cancer. However, particularly for deep HT where phased-array applicators are used to focus electromagnetic (EM) energy to the target region, treatment planning (TP) is required to optimize treatment quality (maximize tumor coverage while minimizing hot-spots in healthy tissue) and dynamically adapt steering.

Materials
An integrated TP framework was implemented to generate MR/CT based 3D patient models, simulate EM and induced heating, optimize temperature, and perform post-processing (thermal dose quantification, visualization, analysis, reporting). Of particular importance is the modeling of perfusion effects (thermoregulation, impact of discrete vessels, etc.). The optimizers implemented can adapt steering in real-time based on feedback during treatment.

Results
The TP system is being used in the clinic to pre-plan and analyze superficial and deep hyperthermia treatments. Dosimetric and thermal measurements in phantoms/volunteers, and comparison with sensor/patient feedback obtained during treatment was used to validate the planning.

Conclusion
A comprehensive HT TP system was developed and successfully employed in research and clinical settings to optimize HT treatment, develop treatment and QA guidelines, design novel applicators, and assess risk, e.g., with metallic medical implants. Improved and validated clinical integration and coupling to real-time information is in progress.
Forward planned modulated electron radiation therapy (MERT) for different anatomical locations: a comparison with pure photon plans

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Objective
To investigate potential applications of forward MERT for different anatomical locations and to compare with the initial photon plans (conventional or IMRT). Both pure MERT and mixed MERT/photon techniques are investigated.

Materials
Beam segments with different electron beam energies according to the distal depth of the target volume were determined. Electron dose calculations were performed with Monte Carlo using the Swiss Monte Carlo Plan. For mixed beam techniques, a sequential optimization was used where the electron dose serves as the basis dose for subsequent photon optimization. Anatomical locations investigated included breast, head and neck and lymphoma.

Results
Overall, pure MERT plans gave poorer dose conformity compared to pure photon plans. However, mixed MERT/photon plans lead to the same dose conformity as pure photon plans. Concerning organs at risk sparing, DVH of MERT-based techniques and pure photon techniques showed that in some cases, better sparing was achieved in the high dose region with MERT-based techniques compared to pure photon techniques but in other cases better sparing was achieved in the low dose region. Additionally, MERT-based plans can reduce the body integral dose by 10-15% compared to pure photon plans in most cases.

Conclusion
A forward MERT based technique offers a promising alternative to pure photon based techniques for carefully selected locations. This work was supported by Varian Medical Systems.
Macro Monte Carlo interface with beam model for treatment planning in proton therapy

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Objective
Recently a macro Monte Carlo (MMC) method has been developed for accurate and efficient dose calculation in proton therapy. This work is focused on the development of an interface between the MMC algorithm and a beam model in order to allow treatment planning for proton beams.

Materials
The beam model interface is based on an existing beam model for modulated scanning beam lines. Based on the beam data of the commissioned beam model and the patient treatment plan, a sampling procedure is defined to provide the particle type, position, direction, energy and weight of the starting particle necessary for the MMC dose calculation. The MMC interfaced with the beam model is validated by comparing sampled position and energy distributions of single spots with those from the already existing beam model. Furthermore, dose distributions in a water phantom for single spots of different energies calculated using either MMC with the beam model interface or the pencil beam algorithm available in Eclipse are compared.

Results
The sampled distributions for the position and the energy within a spot are in good agreement with the corresponding distributions of the existing beam model. The ranges of the depth dose curves of the calculated dose distributions agree within 1 mm, while the dose differences are generally within 2% except close to the surface.

Conclusion
Interfacing the MMC with the beam model allows performing treatment planning for proton radiation therapy. This work was supported by Varian Medical Systems.
Using the Swiss Monte Carlo Plan for inverse treatment planning of MERT

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Objective
For shallow tumors the use modulated electron radiotherapy (MERT) could be advantageous. In this work an inverse optimization for MERT is implemented into the Swiss Monte Carlo Plan (SMCP).

Materials
The inverse planning starts with the selection of the SSD as well as gantry and collimator angles for each electron field. These fields are divided into a grid of beamlets for which the dose distribution is pre-calculated using SMCP. Then a direct aperture optimization (DAO) using simulated annealing determines aperture or weight changes to minimize a cost function. A post processing step corrects for the MLC impact on the dose distributions. For testing purposes, an inverse treatment plan is created for an academic situation and compared to previously obtained forward planning results.

Results
The optimization was successfully implemented into the SMCP. For the academic situation the DAO took about 30 minutes. The comparisons between the 7 field forward and the 3 field inverse planned MERT shows that inverse planning can reduce the dose to the OAR (mean dose from 41% to 38%) without compromising the PTV coverage (V95 from 93.5% to 93%).

Conclusion
The developed inverse optimization can be used for treatment planning of MERT. This work was supported by Varian Medical Systems.
State of submillimeter in vivo dosimetry with Gafchromics

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Objective
To discuss the current state and future needs in our Gafchromic in vivo dosimetry.

Materials
Breast cancer patients with standard fractionation of 2Gy/fx have been followed with in vivo dosimetry during the full course of their radiation treatments. Patients were treated on the TomoTherapy system using either helical or static IMRT delivery. Gafchromic EBT2 and EBT3 films were cut to square pieces of ~1mm². Up to eight points were measured per patient on the breast and supraclavicular regions. The films were affixed to the patients’ skin using surgical tape. Readings were made after 30 minutes and dose conversion performed using in-house MATLAB code.

Results
A total of 595 film measurements, representing 14 total points on four patients, have been performed and analyzed. Daily film setup on the patients was estimated to take 5-60 seconds, representing the full time range observed. Superficial dose without bolus averaged 100cGy to 130cGy for both helical and static treatments. Two of the three points measured under bolus averaged within 1% of the TPS calculated dose. Ten of the 14 total points exhibited STDs greater than that of the film method uncertainty (2σ).

Conclusion
The film method uncertainty (2σ) is estimated at ±2.8cGy for EBT2 and ±1.4cGy for EBT3. Therefore, dose action levels within the 5% radiation treatment goal are easily met for doses in the therapeutic range. Current limiting factors are film positioning precision, the corresponding CT localization, voxel dose averaging, and TPS calculation uncertainties in the buildup region. Interpretation of the in vivo dose measurements is the near frontier.
Pre-treatment QA for VMAT flattening filter free beams with portal imager using GLAAS algorithm

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Objective
To investigate the possibility to use the PV-aS1000 detector on Varian TrueBeam (TB) linac for pre-treatment QA of RapidArc (RA) plans with flattening filter free (FFF) beams.

Materials
The detector response was found adequate for 6 and 10 FFF beams, increasing SDD (e.g. 150cm) to avoid saturation problems with the maximum DR (1400/2400 MU/min). The GLAaS algorithm, already validated to convert PV readings into absorbed dose to water for IMRT and RA pre-treatment QA for standard beam, was extended to FFF. In this study, five different clinical FFF RapidArc plans with prescription dose ranged 7-18Gy/fx were recalculated for 6 and 10FFF, on 4 different TB equipped with MLC and HD-MLC. Agreement was assessed in terms of profiles and gamma index (GAI).

Results
The overall results were highly satisfactory, with a GAI in the field area for 6 and 10 FFF 97.9±2.5% and 98.6±1.6% with 3mm/3%, 92.0±3.5% and 96.6±4.3% for 2mm/2%.

Conclusion
The possibility to use the PV as pre-treatment QA device for RA for FFF beams, combines the flexibility and efficiency of this approach, with the possibility to verify absorbed dose with a high resolution detector (i.e. 0.26 mm at SDD=150cm), aspects particularly interesting in hypofractionated treatment, where small fields are mostly used.
Dosimetric comparison of Acuros XB and AAA with COMPASS-CCC calculations for volumetric modulated arc therapy

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Objective
To analyze the differences between Acuros XB and Anisotropic Analytic Algorithm (AAA) dose calculation with the Collapsed Cone Convolution (CCC) calculations derived from fluence measurements as available in COMPASS (IBA Dosimetry) for volumetric modulated arc therapy (VMAT).

Materials
Five clinical cases were planned with VMAT: Brain, Head and Neck, Thorax, Pelvis and SBRT. To calculate the dose with CCC in COMPASS all fluences were acquired with the iMatrixx-2D detector on a Clinac iX (Varian, Palo Alto, USA), 6MV. These dose distributions were compared with Acuros XB and AAA calculations from Eclipse treatment planning system using 3-D gamma index with distance-to-agreement and dose difference criteria set to: 3mm/3% and 2mm/2% for targets, organs at risks (OAR), 50 and 10% isodose volumes. DVH of OAR and PTV from plan differences were also computed and analyzed.

Results
Study presented good agreement between Acuros XB or AAA and CCC. In particular for the PTV the percentage of points passing the 3mm/3% gamma criteria are 99.7±0.3% for CCCvsAcuros, 98.6±1.0% for CCCvsAAA and 97.0±0.2% for AAAvsAcuros, averaging all cases. From plan difference the mean doses of OAR and targets were within ±1%.

Conclusion
This study showed the good agreement of CCC calculations from measured fluences with respect to both Acuros XB and AAA algorithms from treatment planning system.
SBRT for lung cancer treatments: dosimetric evaluation using FFF beams

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Objective
To evaluate possible dosimetric benefits using flattening filter free (FFF) beams for treatment of lung cancer in stereotactic regimen.

Materials
Two groups of patients with lung cancer were selected: SBRT, 11 pts having PTV diameter 4cm (up to 9.4cm, mean 6.2±1.6cm). All pts underwent 4DCT in 10 respiratory phases. All lesions were planned with RapidArc technology for: flattened 6,10 MV (6,10X), unflattened 6,10 MV (6,10FFF) generated by a Varian TrueBeam. Plans had 2 partial arcs, optimized with PRO3, using the same constraints, procedures of intermediate dose calculation and re-optimization for all beam quality plans. SBRT plans were planned to receive 3x18Gy at mean PTV, while HBRT had prescription of 5x10Gy. Dose distributions were calculated with AcurosXB 11. DVH analysis was conducted on PTV for target coverage and dose homogeneity, and on the omolateral lung deducted the target volume.

Results
The target coverage and dose homogeneity was the best for 6FFF beams, followed by 6X, while the worst was for 10X: D98%=97.6±0.4 and 95.6±1.4% for 6FFF and 10X respectively for SBRT, D98%=95.6±2.0 and 93.6±3.6% for HBRT. Mean lung dose was 3.5±0.7,3.6±0.8,3.8±0.8,4.0±0.8Gy for 6FFF,6X,10FFF,10X respectively for SBRT, and 7.5±2.3,7.7±2.4,7.9±2.4,8.2±2.5Gy for HBRT.

Conclusion
Stereotactic treatments for small lung cancer can dosimetrically benefit from the usage of FFF relative to the flattened beam, and lower energy would deliver less peripheral dose.
Towards a more precise dynamic scanned proton treatment – online deformable motion reconstruction using PCA motion model

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Objective
Gantry2 is equipped with innovative image guided system which can track tumour motion in fluoroscopy model. However, for scanned treatment, supplementary information on the dense motion field is compulsory. Any sparse motion is not sufficient to describe the deformable behavior of the entire ROI. We proposed a method here, which can online reconstruct deformable motion from measurements of tractable surrogate motion.

Materials
Principle Component Analysis (PCA) is applied to 11 4DMRI liver motion subjects respectively for building patient specific motion models. For 30 breathing cycles (contain irregular patterns), surrogate motion from fiducial markers alone, diaphragm alone and combined are used as predictors to estimate dense motion field. 4D dose calculations are then used as a verification tool to evaluate its performance.

Results
Averaged (median) over 11 cases, for 99% of predicted positions, an error amplitude of better than 1.76mm can be achieved. 4D dose distributions shown a high similarity (Vdiff<=5% is 4.5%) between plans considering either reconstructed motion or ground truth motion. Significant differences can be seen, if motion of the whole geometry is considered as a rigid translation by only following mean 2D marker trajectory.

Conclusion
Our results has shown that online deformable motion reconstruction is feasible, and emphasized the necessity of predicting spatial non-rigid motion and the “lost” motion in depth due to the BEV imaging geometry. Interestingly, diaphragm motion has been found out as a good predictor, implying that fiducial markers might not be compulsory if a PCA model is used.
VMAT planning for Elekta linacs in the Varian planning system Eclipse: a comparison study of VMAT plans with fixed field IMRT plans

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Objective
For different treatment planning systems it has been shown that plan quality of VMAT is comparable to IMRT. In the latest release of Eclipse a VMAT optimizer for Elekta linacs is implemented. This study compares VMAT plans created with this optimizer against IMRT plans for various main tumour regions.

Materials
181 clinical IMRT plans were selected for this study including 40 cervical, 73 head and neck, 12 brain, 11 breast and 45 prostate cancer cases. For these cases VMAT plans were generated in Eclipse using a VMAT optimizer for Elekta Synergy linacs. To standardize the optimizing process, tumour region specific optimizing templates were created. Based on these templates two VMAT plans were generated without interference of the operator: with one arc (1A) and with two arcs (2A). All plans were evaluated by target coverage, homogeneity and conformity; the organs at risk (OAR) were analysed according to plan objectives such as mean and maximum doses.

Results
The differences between the considered techniques are small and depend mainly on the tumour region. For template-based 2A plans in 27 cases out of 181 an exceeding of the objectives for one or more OAR was found, in 13 cases an over- or under-dosage in the PTV in direct comparison to IMRT. For 1A plans 30 cases showed an exceeding of the OAR objectives, 25 for the target volume coverage.

Conclusion
Eclipse is able to achieve comparable plan quality for Elekta VMAT delivery technique to that of IMRT in terms of target coverage and critical structure whereas plans with 2 arcs show less exceeding of the objectives than plans with 1 arc.
Collapsed cone algorithm and its impact on dose distributions in HDR brachytherapy for partial breast irradiations

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Objective
To evaluate the impact of dose calculations using a test version of the collapsed cone (CC) algorithm from Nucletron on dose distributions in HDR brachytherapy for partial breast irradiations.

Materials
In a first step, the CC algorithm is validated by comparing CC with Monte Carlo (MC) and TG43 calculated dose distributions. In a second step, 10 HDR treatment plans of partial breast irradiation previously calculated with MC and the TG43 formalism are recalculated using the CC algorithm. Clinical relevant DVH parameters of partial breast irradiations of the plans are determined and compared.

Results
The validation shows good agreement between CC and MC calculated dose distributions. For a sufficiently large CT scan length of the patient, calculated doses performed with CC agree generally within 1% with dose distributions simulated with MC. Dose calculations based on TG43 overestimate V(Dref) and D(PTV,50%) as compared to the CC calculations both by about 2%. Maximal doses to the skin, D(Skin,0.5ccm), and to the rips, D(Rips,0.5ccm), calculated using CC are on average about 5% and 3% lower than maximal doses calculated with the TG43 formalism, respectively.

Conclusion
CC is an accurate dose calculation algorithm. Its implementation into brachytherapy improves the accuracy of dose prediction compared to today’s treatment planning systems. This work was supported by Nucletron.
Log file based dose calculations as a quality assurance tool in scanned beam proton radiotherapy

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Objective
Proton therapy with actively scanned beams requires time consuming quality assurance procedures. To reduce these, we propose an independent calculation system based on pre- and post-treatment data to reconstruct the planned and delivered dose.

Materials
Our treatment control system consists of an active (TDS) and passive (TVS) part, both driven by ‘steering’ files generated via the treatment planning system. From these, pre-treatment doses can be reconstructed. In addition, post-treatment doses can be reconstructed from log files written by the TVS which the actual measured parameters of the delivery (position, MU etc). Both have been used to reconstruct doses for real and simulated delivery.

Results
For successful fraction delivery, gamma analysis (2%, 2mm) shows a 99% agreement of reconstructed and planned dose in the CTV. The reconstructed dose is sensitive to delivery errors (e.g. deviations of single spot positions) and can illustrate the effect of small systematic errors, which are not picked up by a spot by spot comparison of log and steering file data. The reconstructed doses agree with measurements done with a CCD system within calculation accuracy.

Conclusion
Steering and log file based dose calculation were shown to be an accurate tool for assessing the correct delivery of dose both before and after treatment. Furthermore, they are a potential tool in the definition of tolerances for quality checks by exploring the clinical significance of possible delivery errors.
A breathing anthropomorphic phantom for experimental studies of moving tumors in scanning proton therapy

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Objective
A realistic breathing anthropomorphic thorax phantom has been designed and constructed for comprehensive dosimetric studies of mobile tumors in the lung region.

Materials
The phantom is metal-free and is therefore both CT and MRI compatible. The air-tight thorax is filled with a special foam which allows to distribute inflated air into the entire volume. A rib cage enclosing the thorax is formed from authentically shaped ribs. Air inflation into the thorax leads to realistic rib cage expansion and tumor motion, and is performed with a programmable respiratory device. Delivered dose distributions can be measured with an ionization chamber or Gafchromic films.

Results
In the main direction, tumor motions up to 3cm can be achieved. Material densities were extracted from CT measurements and are similar to those of human tissues. An external `skin` motion has been recorded using both an optical distance sensor and the Vision RT system. Finally, first scanned proton beam tests have been performed with the phantom. Planned and delivered doses (1Gy, measured using GafChromic films) in the static case agreed well, with a standard deviation of dose in the tumour of 3%. When measured with a 1cm amplitude motion, the mean dose to the tumour reduced to 0.85Gy, with a standard deviation of 14%.

Conclusion
The breathing phantom is a valuable tool for extensive studies of mobile tumours, and allows us to simulate all treatment steps from imaging through the delivery and `in-phantom` verifications.
Geometrical and dosimetrical evaluation of a prototype motion tracking system using the treatment couch

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Objective
Technical evaluation of a one dimensional prototype tracking system using the treatment couch.

Materials
A closed loop tracking system was built in house. It consists of the topometrical patient repositioning system TOPOS, and the commercially available treatment couch Protura (CIVCO). TOPOS was used to detect movements of the patients’ surface. A proportional (P) and a proportional-integral (PI) controller were implemented for disturbance rejection. Ziegler and Nichols tuning rules were used to find appropriate parameters for the controllers. Different breathing amplitudes were tracked and the residual amplitude was measured using a gating system (Varian). Additionally, tracked dose distributions were compared to static dose distributions as well as dose distributions containing motion artefacts.

Results
The residual amplitude using the P controller was below 1mm and using the PI controller below 0.5mm. Dosimetrical verification for open fields (gantry perpendicular to motion) showed 100% gamma agreement index (GAI) (2mm, 2%) between tracked and static fields, compared to 89% between fields radiated on the static phantom and the moved phantom. For VMAT treatments (full arcs), the GAI (1mm, 1%) between tracked and static fields was 99.5% (+/- 0.2%). Even during the simulation of patient coughing by a sudden motion (4cm) the system did not get instable.

Conclusion
Our initial prototype system was improved by the PI feedback controller. This led to reduced residual motion, and excellent dosimetrical results.
Hypofractionated radiotherapy has the potential for second cancer reduction

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Objective
A model for carcinoma and sarcoma induction was used to study the dependence of carcinogenesis after radiotherapy on fractionation.

Materials
A cancer induction model for radiotherapy doses including fractionation was used to model carcinoma and sarcoma induction after a radiation treatment. For different fractionation schemes the dose response relationships were obtained. Tumor induction was studied as a function of dose per fraction.

Results
If it is assumed that the tumor is treated up to the same biologically equivalent dose it was found that large dose fractions could decrease second cancer induction. The risk decreases approximately linear with increasing fraction size and is more pronounced for sarcoma induction. Carcinoma induction decreases by around 10% per 1 Gy increase in fraction dose. Sarcoma risk is decreased by about 15% per 1 Gy increase in fractionation. It is also found that tissue which is irradiated using large dose fractions to dose levels lower than 10% of the target dose potentially develop less sarcomas when compared to tissues irradiated to all dose levels. This is not observed for carcinoma induction.

Conclusion
It was found that carcinoma as well as sarcoma risk decreases with increasing fractionation dose. The reduction of sarcoma risk is even more pronounced than carcinoma risk. Hypofractionation is potentially beneficial with regard to second cancer induction.
Retrospective analysis of target volume dose coverage using CBCTs acquired for Accelerated Hypo-Fractionated Radiation Therapy (AHFRT) in lung cancer.

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Objective
To assess target volume dose coverage using CBCTs acquired for AHFRT.

Materials
Nine patients (pts) were investigated in this study. Dose prescription was 60 Gy to the PTV (ITV plus 5mm margins) delivered in 3, 5 or 8 fractions with RAPIDARC, using 3 to 5 arcs, 6 MV energy beam and the Novalis TX linac. Patients were supine on a cushion or a thoracic support. All but 2 pts had arms over the head. ExacTrac was used on pts bony structures enabling fine 6D table position movements followed by CBCT images for ITV 3D positioning. During treatment ExacTrac snap verifications monitored the patient. Twenty CBCTs were randomly selected to re-calculate dose coverage to the target in patients’ treatment position, having tested the feasibility on phantom (results presented separately). DVHs were analyzed and for 3 pts, session dose distribution reproducibility was assessed.

Results
Mean median dose percentage difference coverage (CT-CBCT) PTV and ITV was 0.01 ± 2.41 and -0.08 ± 2.67 respectively. Mean minimum and maximum dose percentage difference coverage (CT-CBCT) of ITV was 0.415 ± 2.83 and -1.21 ± 2.62 respectively. One patient showed systematic differences larger than -4%, due to image CBCT problems and without this patient, previous reported values changed to 0.81 ± 1.46, 0.88± 1.36, 1.23 ± 2.11and -0.2± 0.93. Dose targets coverage reproducibility, means standard deviation was less than 1.8%.

Conclusion
This preliminary study showed that good patients positioning leads to dose distribution reproducibility respect to simulation as verified using CBCTs.